

Birth of colliding beams in Europe, two photon studies at Adone

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Abstract. This article recalls the birth of the first electron-positron storage ring AdA, and the construction of the higher energy collider ADONE, where early photon-photon collisions were observed. The events which led the Austrian physicist Bruno Touschek to propose and construct AdA will be recalled, starting with early work on the Widerøe's betatron during World War II, up to the construction of ADONE, and the theoretical contribution to radiative corrections to electron-positron collisions.

1. Introduction

Photon-photon physics started its long way towards measurement and observation long time ago. Theoretical calculations of $\gamma\gamma$ processes were developed early before the advent of QED, and then refined in mid 1950, as described in other contributions to this session. The first phenomenological studies started with electron-positron collisions, at VEPP-2 and ADONE. The construction of ADONE has been proposed by Bruno Touschek in 1960 soon after AdA, the first storage ring ever to be built and function, where electron-positron collision were first observed [1].

AdA opened the way to higher luminosity, higher energy, more modern machines and in this contribution we shall recall the birth of AdA, and the construction of ADONE, and the events which led to the first observation of electron-positron collisions. Since much has been written on this subject, to avoid repetition we shall mostly discuss here less known parts of the story of AdA, Touschek and ADONE, in particular focusing on the extraordinary combination of events which allowed Touschek to propose AdA in February 1960. The main reference work for Touschek's life and his contribution to the construction of both AdA and ADONE is the biography written by E. Amaldi after Touschek's death in 1978 [2]. Further details about Touschek's life and science can be found in [3, 4, 5, 6].¹

Touschek's life spans Europe in space and time, from before to after the Second World War, from the native Austria to Italy, where he gave his greatest contribution to modern day science by proposing the construction of the first electron-positron storage ring. Fig. 1 summarizes the major stages of his life.

¹ Volume [5] and the LNF internal Notes since 1953, mentioned later in this article, are available at <http://www.lnf.infn.it/sis/>.



Figure 1. A cartoon showing the main stages of Bruno Touschek's life.

The milestones in Touschek's scientific life can be identified as having taken place in the following major periods:

- 1943-45: during these years, Touschek was in Germany, and worked with Rolf Widerøe to build a betatron;
- 1947-1952: he was awarded his Ph.D, published several papers on quantum field theory, double β -decay and meson physics, and was involved in the design and construction of an electron-synchrotron;
- 1953-59: these are the years during which Bruno Touschek, who had been given a position in Rome with the newly established Istituto Italiano di Fisica Nucleare (INFN,), deepened his knowledge in theoretical physics, studying the new symmetries and the breaking of the old ones;
- 1960-64: this is the period for which his contribution to modern science is best known, the proposal and construction of AdA, the discovery of the Touschek effect in Orsay, and the first ever observation of e^+e^- collisions;
- November 1960 onwards: Touschek drafted a proposal for a large collider, ADONE, and then followed its construction and developments.

2. How Touschek learnt to build accelerators

Bruno Touschek learnt the art of building accelerators in Germany, during World War II, while working on a secret betatron project, led by the Norwegian engineer Rolf Widerøe [7], financed by the Aviation Ministry of the Reich, the *Reichsluftfahrtministerium* (RLM). The encounter and collaboration of Touschek and Widerøe, which ultimately led to the AdA proposal in 1960, follows from a series of rather extraordinary coincidences, which originated on the one side in Norway, in Trondheim and Oslo, and on the other in Vienna and Munich. We know for sure that in September 1943 Touschek and Widerøe were already working together on the betatron project, and in fact it is at that time that Widerøe mentioned to Touschek the idea of oppositely

charged colliding particles. But how did they meet? One was a 22 year old physics student, born in Vienna from a Jewish mother, who died young, while his father, who later remarried, had been an officer in the Austrian army. The other was an experienced engineer from Oslo, who had done early work on the theory and construction of accelerators for the PhD he had obtained in Karlsruhe. Not irrelevant to the story is that Widerøe's brother had been working for the Norwegian underground and was kept prisoner by the Germans. The desire to help him is one of the reasons Widerøe ultimately accepted to come to Germany to build a betatron. Touschek had left Vienna to continue his studies in physics in the relatively anonymity of Hamburg and Berlin, after he had to stop attending classes at the University, where he had enrolled to study physics, and where he had already shown excellence. In Fig. 2, we show two photographs of Touschek and Widerøe.



Figure 2. At left, a photograph of the 18 year old Rolf Widerøe from [7] . At right, a photograph of Bruno Touschek from his passport. It was probably prepared in 1939, for his last travel to Italy to visit his maternal aunt Adele, nicknamed Ada.

We shall try to separately outline the two stories which came together in Berlin in 1943, and will start describing the path which brought Touschek to learn of Widerøe's work. Bruno had left Vienna, where he was born in 1921. His Jewish origin from mother's side had brought many difficulties after the annexation of Austria to Germany in 1938. Enrolled at the University of Vienna to study physics in 1939, at the end of the academic year he had to stop attending classes and could only study at home with books borrowed by his young teacher Paul Urban. Thus he moved to Germany, under the patronage of Arnold Sommerfeld, who had been contacted by Bruno about some small errors in the fundamental treaty *Atombaum und Spektrallinien*, which Bruno had started studying. In February 1942 Bruno was in Munich, visiting Sommerfeld, and then went to Hamburg, where he started attending courses at the University, studying and doing odd jobs to make a difficult living. In Figs. 3 and 4, we show two drawings from this period, which Touschek had included in letters to his father and step mother.² Under Sommerfeld's recommendation, Bruno was unofficially attending classes at both University of Hamburg and University of Berlin, and frequently moved between the two cities. Sometime, probably in fall 1942, he met a girl, also half-jewish, who worked in Berlin, at Loewe-Opta, a radio and television manufacturing company, and suggested he could also obtain a job there. And so it happened

² In these letters Touschek addresses them as *Dear parents*.



Figure 3. A drawing by Bruno Touschek, from a 23 August 1942 letter from Hamburg.

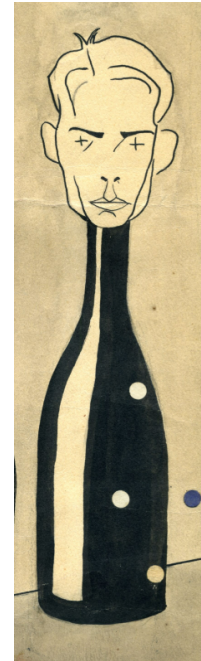


Figure 4. A 1942 portrait of Bruno Touschek, included in a letter to his parents.

that Bruno ended up working with Karl A. Egerer, who was at the time the director of a special department within the company, that was now also producing electronic devices of war interest. Egerer was the editor of the scientific journal *Archiv für Elektrotechnik*, too. In this journal, in 1928, Rolf Widerøe had published his article on the theory of betatrons and to this journal, as we shall presently see, he would send on September 15, 1942 an article entitled *Der Strahlentransformator*, where he presented the proposal to construct a 15 MeV betatron, and even gave hints about a more powerful 100-MeV machine. This is the article, accepted but never published, which was to put in motion the RLM betatron project. We have in fact some evidence from a February 1943 letter to his parents, that Touschek read this article, in his capacity as assistant to Egerer, and commented upon it to him. In this letter, Touschek tells his parents that Egerer became excited and started making *crazy* plans for some war related project to present to the RLM, or even to Heisenberg.³ Egerer was in contact with other scientists and engineers gravitating around various high ranking officers at the RLM, and it is suggestive to think that this is how the project must have reached them and started its way to realization. Once accepted, the article was classified and could not be published.⁴ At this point, we shall now step back to see the train of events which made Rolf Widerøe submit the article and then come to Hamburg in September 1943 to build the 15 MeV German betatron.

In the United States, the 1928 article by Widerøe had interested accelerator scientist. His first unsuccessful attempt to build a betatron inspired Ernest Lawrence to build the first cyclotron [8] and was later central to the construction of the betatron by Donald Kerst, who reported it in his *Physical Review* articles on the betatron [9, 10, 11]. It is worth noticing here that the same articles were the subject of the 1941 thesis work by Giorgio Salvini, the physicist who would

³ This letter and a translation of it were published in [3].

⁴ A copy of the article in its proofs was kindly provided to us by Aashild Sørheim, of the University Radium Museum in Oslo. A more detailed account of the events involving the unpublished article can be found in [3].

be called in 1953 to build the Frascati electro-synchrotron and who, in 1960, as Director of the Frascati National Laboratories, approved the construction of AdA.

The issue of the *Physical Review* with Kerst's article was one of the last to reach Nazi-occupied Norway and it was read, in the fall of 1941, by the physicist Roald Tangen, from the Physical Institute of Trondheim University. In Tangen's words [6]: *I can well remember the events of 1941 [...] In the autumn of 1941 the Physics Association invited me to give a lecture on modern accelerators in Oslo. We had been denied access to American magazines by then, and we were completely ignorant of the betatron. A few days before my trip to Oslo a single copy of the Physical Review arrived in Trondheim by ordinary mail. Mysteriously, it had found its way to us. It contained an article by Donald Kerst on the first working betatron. This fitted well in my lecture in which I went on to explain that Kerst mentioned a German doctorate thesis by a R. Widerøe in which a fundamental equation for the betatron was developed. I did not know anyone by the name of Widerøe at the time, but I told my audience that the name indicated that he could be a Norwegian. As we were to discover soon enough, Rolf Widerøe was sitting in the auditorium.*

Widerøe had left working on accelerators after his thesis work, and had joined the Norwegian branch of Brown-Boveri. But his interest was rekindled by Kerst's article and he immediately went back to work to propose a similar machine to be built in Europe. Thus, in September 1942 he submitted the article to the *Archiv für Elektrotechnik*. And here is where the two stories of Touschek and Widerøe meet. In his autobiography, Widerøe writes : *A very strange thing happened when my first article appeared. One day, it must have been in March or April 1943, several German Air Force officers came to NEBB [Norsk Elektrisk og Brown Boveri] wanting to speak with me. Norway had been under occupation since April 1940. I cannot remember exactly whether there were two or three of them. ... They asked whether we could go to the Grand Hotel together to talk about something. ... They said that it could be a matter of some importance to my brother ... The German officers hinted that it may be possible to release my brother if I helped them. This decided things for me, and I agreed to go to Berlin. Two days later I was flown there for a short visit, and they told me about their plans to build betatrons.*

The coincidence of dates, namely Touschek's reading the submitted article, in mid February, and the visit to Widerøe by the German officers in Spring 1945, suggests that, following Touschek's comments on the article, Egerer may have contacted the RLM. The interest of the German war authorities in betatron research and possible war applications is documented in [12] and this may have prompted the contacts with Widerøe in Oslo. We also notice that Widerøe had previously tried in vain to obtain a more lenient treatment of his brother's imprisonment conditions [7, 13]. Several groups at the time were quite interested in the possibility of having sources of artificially accelerated particles. And even if it was already clear that the betatron could be employed only as a source of X-rays used mainly for medical purposes, building such a machine was of course an exciting scientific project per se.

Bruno worked alongside with Widerøe from 1943 until March 1945. During this period Touschek contributed with theoretical work, the great part of which was later used for his thesis work at Göttingen, at the end of the war. In particular he tackled the problem of the energy losses due to radiation damping, which would define an upper limit for the energy obtainable with the betatron. As the war approached its end, the betatron, which was almost completed, was moved from Hamburg to Kellinghusen, a supposedly safer location, 40 Km North of Hamburg, in the property of one of the scientists of the betatron group. As recounted many times, around March 15th, Touschek was arrested and kept in the infamous jail of Fuhlsbüttel. He received some comfort from Widerøe's visits, which brought him books and cigarettes, and promises of release, but the future destination of prisoners in this jail, mostly Jews, was the Kiel concentration camp, some 30 Km North of Hamburg. And it was to this camp, as the allied troops were approaching Hamburg in mid April, that Touschek was directed, together with other 200 prisoners, guards

in front and guards at the back. Luckily for him and for science, Touschek did not reach Kiel: he fell to the ground, being sick and burdened by a load of books and few belongings, was shot and left for dead on the side of the road. Further developments of Touschek's story during the war are outlined in [3], where the two letters written by Touschek to his family in June and October 1945 are presented.

3. The birth of e^+e^- colliders

The construction of AdA and its final success is the work of many scientists. Three, among them, had a pivotal role: Bruno Touschek, who proposed it and contributed to its commissioning, Giorgio Salvini who made the Frascati synchrotron to work in 1959 and created, from nothing, a pool of scientists, technicians and engineers of world capacities, and Edoardo Amaldi, Fermi's youngest collaborator in Rome before the war. Edoardo Amaldi, who was one of the leading actors in the resurgence of physics in Italy and in Europe after the war, called to Rome both Touschek and Salvini, two scientists who had, in their training, the knowledge and the mindset of constructing accelerators.

In Fig. 5 we show Touschek with Amaldi and other scientist friends, during a excursion to the Tuscolo hills, above the town of Frascati. During his earlier period in Rome, where



Figure 5. Bruno Touschek (center), in Italy in 1953, at Tuscolo hills with Edoardo and Ginestra Amaldi to his right.

he joined as INFN researcher in 1952, Touschek does not seem to have been interested to the synchrotron work. He was keen in expanding his knowledge of theoretical physics and engaged in the challenges posed by the renewed post-war activities and quantum field theory formulations, as testified, notably, by his intense correspondence with Wolfgang Pauli during the 1950s. But as the synchrotron approached its completion, his interest grew, and in 1959, he was coming regularly to the Laboratory, attending seminars and meetings. It was one such seminar, by the Director of the High Energy Physics Laboratory of Stanford University, Wolfgang Panofsky, which seems to have ignited the spark which started AdA. A first reconstruction of this event can be found in [6], where the sources of different recollections are discussed. A possible date for this seminar is October 26th, 1959, since the list of 1959-60 seminars at Frascati Laboratories shows a

seminar by Panofsky on that day. Nicola Cabibbo, who had graduated with Touschek a few years before, recalled ⁵ that after this seminar and a discussion on the electron-electron tangential ring collider built in the US, Touschek asked: *Why not using electrons against positrons?* According to Cabibbo, it was thus during this seminar that the idea of having electrons and positrons circulate and collide within the same ring, was put forward by Bruno. In the months to follow he pursued the idea and started making some calculations for a draft proposal, which he presented on February 17th, 1960 at a meeting called to discuss the future programs of the Laboratory.

He had envisaged to modify the Frascati electro synchrotron to make it into a storage ring, but this was unthinkable given the expectations of the Frascati physicists to start experimentation with the synchrotron set-up. On February 18th, the day after the meeting, he then started work on a realistic proposal, whose first page is shown in Fig. 6. As a comment to the intense work,

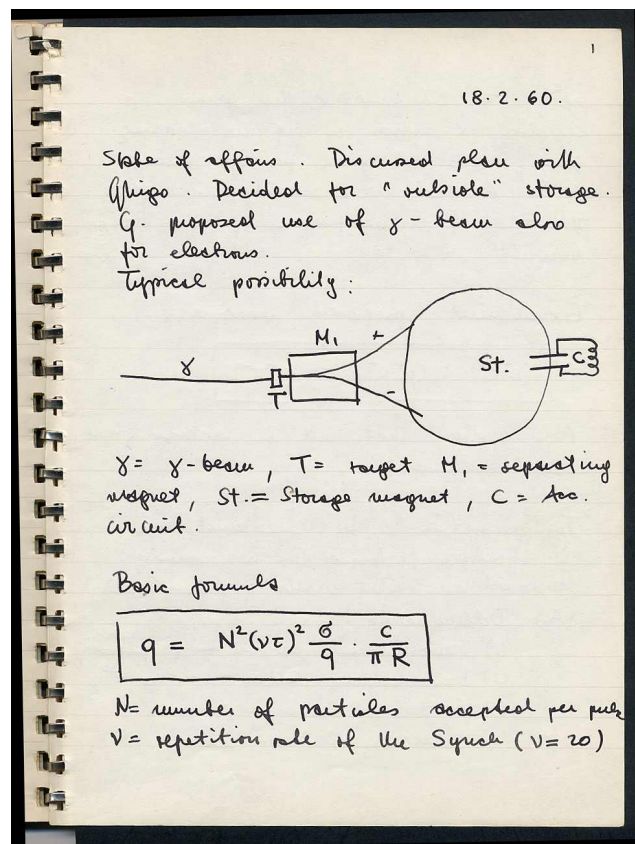


Figure 6. First page of the notebook where Touschek started the actual proposal for the construction of AdA.

which started taking place in those months, such as the comprehensive calculations of expected processes [14], we show two (later) drawings by Bruno Touschek, in Fig. 7.

The proposal was approved on March 7th and in less than one year AdA started functioning [15, 16]. As Pierre Marin would later recall [17], a team of first class scientists designed and built a small ring in which they made electrons and positrons circulate, in opposite directions, for hours. They were Carlo Bernardini, Gianfranco Corazza, Giorgio Ghigo, Mario Puglisi, Ruggero

⁵ Bruno Touschek's life during the period spanning from his arrival in Italy in 1952 to the building of AdA and ADONE is outlined in the docu-film *Bruno Touschek and the art of physics*, by E. Agapito and L. Bonolis, ©INFN 2003



Figure 7. Two drawings by Bruno Touschek.

Querzoli, Giancarlo Sacerdoti, Peppino di Giugno and, of course Bruno Touschek. AdA started working in February 1961 but the road to prove the viability of this type of accelerator was long. It took two years and the transfer of AdA to Orsay before obtaining proof that annihilation had taken place.⁶

4. Photons with AdA and two photon observations with ADONE

AdA's luminosity had been too low to observe annihilation into final particles. This had been true in Frascati, but remained true even after AdA had been transported to Orsay to make use of the higher intensity of the electron beam from the linear accelerator, jokingly called by students and researcher's alike *OLGA*, Orsay Linear Great Accelerator. Instead, the proof of collisions had come from the observation of events consistent with single bremsstrahlung [18], namely

$$e^+e^- \rightarrow e^+e^-\gamma \quad (1)$$

Touschek however had been firmly convinced that such type of machine would work, and, as early as November 1960, less than a year after he had proposed to build AdA, a proposal to build a much bigger and more powerful machine was put in writing and presented to the Frascati Laboratory management. In Fig. 8 we show the typewritten draft, which was transformed in a joint internal laboratory note [19] a few months later.

AdA remained in Orsay, at the Laboratoire de l'Accélérateur Linéaire, two years, 1962-1964. During this time, important effects, such as the Touschek effect [20], were discovered. After AdA's final measurements in Orsay in 1964 and the confirmation of collisions through Eq. (1) [1], the Italian team returned to Rome and Frascati, and the construction of ADONE started in earnest. Touschek followed the construction of ADONE, often contributing to discussions about beam instability problems, as described in [21]. He was also particularly worried about radiation problems, whose calculation became the central focus of the theory group gathered around him in Frascati. Calculations of radiative effects at ADONE's energies had initiated

⁶ The transfer of AdA to Orsay is described in the docu-film *Touschek with AdA in Orsay*, by E. Agapito, L. Bonolis and G. Pancheri, ©INFN 2013.

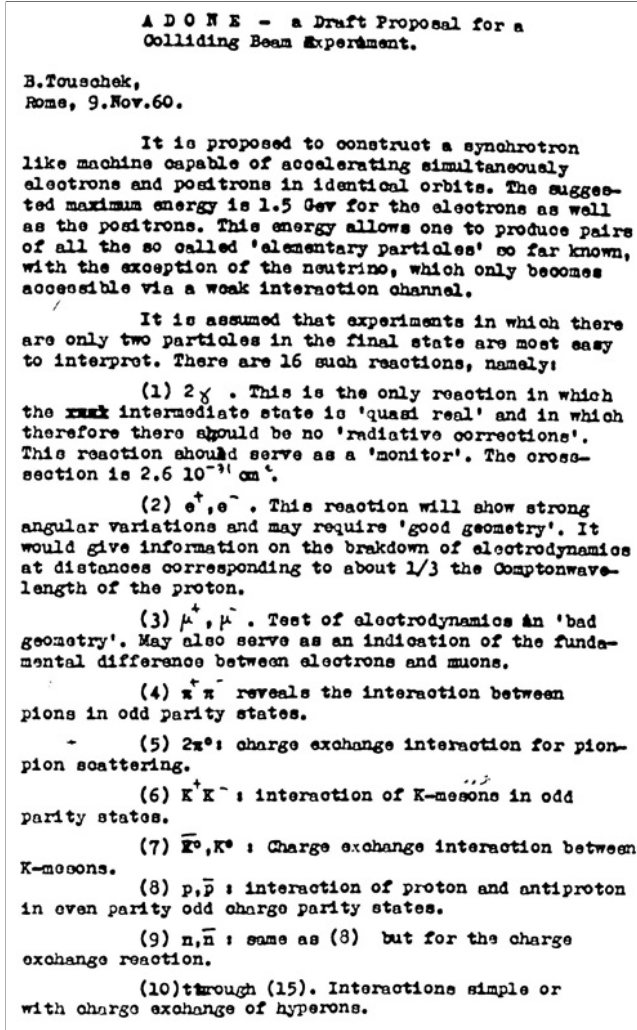


Figure 8. At left we show the draft of the proposal for the construction of ADONE prepared by Bruno Touschek as soon as he was certain that the storage ring principle of AdA was working. Notice the value of the c.m. energy he proposed, namely 3 GeV, chosen so as to observe pairs of all the particles known at the time. At right Bruno Touschek in a photograph in the second half of 1950s and one of his drawings, most probably from the early AdA period, elaborated by C. Federici.

with the single bremsstrahlung, and continued, under Touschek's leadership and guidance, with double bremsstrahlung [22] and photon resummation to all orders [23, 24, 25, 26]. ADONE started functioning at the end of 1968 and began taking data in 1969.

Concerning two photon processes, early in its operation ADONE observed the process which had been proposed by Touschek as monitor for the machine luminosity, i.e. annihilation into two photons:

$$e^+ e^- \rightarrow \gamma\gamma \quad (2)$$

This process, which was observed in Novosibirsk with VEPP-2 [27] and in Frascati, with ADONE [28] in the range with $E_{beam} = 0.7 - 1.2 \text{ GeV}$, was aimed at verification of QED. Other channels of annihilation into pairs of muons, pions, kaons followed, as Touschek had envisaged in his draft proposals.

Soon, both ADONE and VEPP-2 reported the observation of the more complicate final state

$e^+e^- \rightarrow e^+e^- + X$, such as production of an electron-positron pair accompanied by hadrons, or by a second electron-positron pair, or a muon pair. As recalled in the contribution to this conference by Elena Pakhtusova, the first observations of the process

$$e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-e^+e^- \quad (3)$$

were made with VEPP-2 [29] and with ADONE [30]. The ADONE results had also been earlier reported at the 1971 Bologna Conference in April,⁷ and at Cornell,⁸ in August 1971 [31].

Soon, there followed the first observation of the process

$$e^+e^- \rightarrow e^+e^-\gamma\gamma \rightarrow e^+e^-\mu^+\mu^- \quad (4)$$

which was reported in [32]. Later, in 1979, the results of various other measurements of the two photon collision channels at ADONE, namely

$$e^+e^- \rightarrow e^+e^- X \quad X = \gamma\gamma \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \eta'(958) \quad (5)$$

which had been taken in the energy range $\sqrt{s} = 750 = 1500 \text{ MeV}$, were reported in [33]. The complete history, as well as the theoretical developments which led to this field of photon-photon physics, can be found in other talks in the historical session of this conference. In particular, the theoretical developments, to which the group in Frascati and Rome contributed as well, are illustrated in the talks by I. Ginzburg and F. Kapusta.

As a final comment to this brief historical contribution, we show in the right hand panel of Fig. 8 a photo of Bruno Touschek, with his well known drawing entitled *Magnetic discussion*.

Acknowledgements

G.P. thanks Valery Telnov and the other organizers, who have invited her to present this talk and allowed it to be done remotely. The collaboration of the Communication Service of Frascati National Laboratories is gratefully acknowledged. We are also very grateful to the Touschek family who holds the copyright of photos and drawings by Bruno Touschek and provided us with unpublished material from Touschek's letters home during WWII.

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⁷ International Conference on Meson Resonances and Related Electromagnetic Phenomena, Bologna 1971.

⁸ The International Conference on Electrons and Photons Interactions, Cornell 1971.

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